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ReacTec Limited
ETTC,
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EH9 3JL, UK

Patents ADP number *(if you know it)*

8286551002

If the applicant is a corporate body, give the country/state of its incorporation

United Kingdom

4. Title of the invention

"Improvements in or relating to Vibration Control"

5. Name of your agent *(if you have one)*

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Date
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12. Name and daytime telephone number of person to contact in the United Kingdom — John Cooper — 0141 307 8400

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Improvements in or relating to Vibration Control

The present invention relates to improvements in or relating to vibration control, and in particular to a variable damper, a device incorporating a variable damper and to a method of variably damping relative motion between two members.

There are many situations where it is desirable to control or damp the motion between two objects. One way of doing so is to use a magnetorheological device, as described for example in US 2,575,360. Magnetorheological fluid (MRF) contains a suspension of paramagnetic particles, such that when a magnetic field is applied, the particles align with the field thus effectively increasing the viscosity of the fluid.

A magnetorheological device typically contains an electromagnet which generates a magnetic field when current is passed through its coil. One moving part can be enclosed within an MRF chamber such that when

the magnetic field is applied, there is opposition to relative motion of that moving part with another moving part.

US 5,492,312 describes a magnetorheological device wherein a bolt and baffle plate assembly is contained within an MRF chamber, the fluid in which can have a magnetic field applied to oppose relative motion between the assembly and an outer housing, thus damping motion in up to six degrees of freedom. An electromagnetic coil is formed around the outer periphery of the device.

However, design considerations have thusfar limited the application of magnetorheological devices for use in devices where the forces that need to be controlled are relatively high. For a device to support applications such as those identified, the off-state force, namely the minimum force required to induce relative motion between the movable parts, needs to be low. This is difficult to keep low because of the high density of the MRF, which can only be reduced at the expense of its damping effectiveness when a magnetic field is applied.

Furthermore, an electromagnet can be variably controlled such that the magnetorheological device provides varying levels of damping. However, for such control to be properly refined, there is a requirement that the forces that would be expected to be applied to the device in use fall within the force bandwidth, namely the off-state force and the

opposition force provided when the electromagnet is fully activated.

Examples of applications where there are no such effective solutions include skis, snowboards, and other sporting equipment such as golf clubs, tennis rackets, polo mallets, and in power tool applications such as drills for industrial of domestic purposes.

The inventors of the present invention have previously described a vibration control system that is of particular effectiveness to skis, as published under number WO 03/049821. Here, MRF flex actuators are provided to provide single axis control. However, this solution does not provide effective multi-axis control, as may be required in other applications such as snowboards.

According to a first aspect of the present invention, there is provided a variable damper comprising;

an outer member comprising a magnetically conductive sleeve, and

an inner member comprising an electromagnet; wherein

a chamber between the outer and inner members is at least partially filled with magnetorheological fluid (MRF), such that when a magnetic field is applied to the chamber, the effective viscosity of the fluid increases such that relative motion of the inner and outer members is opposed;

the region between the electromagnet and the sleeve defining a control region in which the magnetic field is concentrated.

According to a second aspect of the present invention, there is provided a method of variably damping relative motion between an outer member comprising a magnetically conductive sleeve and an inner member comprising an electromagnet, wherein a chamber between the outer and inner members is at least partially filled with magnetorheological fluid (MRF), the method comprising the step of applying a magnetic field to the chamber, increasing the effective viscosity of the fluid increases to oppose the relative motion of the inner and outer members, where the region between the electromagnet and the sleeve defining a control region in which the magnetic field is concentrated.

As described below, the sleeve provides a return path for the magnetic flux.

Preferably, the sleeve comprises two end surfaces, each in a plane perpendicular to the central axis of the electromagnet and spaced outwardly from an end of the electromagnet, and a body surface centred around the axis of the electromagnet and spaced outwardly from the electromagnet.

Preferably, in a rest position in which no magnetic field is applied, each end surface is at a first distance from an end of the electromagnet, and the

body surface is at a second distance from the electromagnet.

The first and second distances represent variables that define the size and shape of the control region. Here, the distances as measured from the electromagnet are the distances that are relevant. However, the electromagnet may be encased within a housing, and the first and second distances may be more conveniently defined as being the distances between the housing and the sleeve.

Preferably, the first and/or second distances can be minimised in order to reduce at least one degree of freedom of the relative motion of the inner and outer members.

Preferably, the outer perimeter of the chamber is bounded by an inner surface of the outer member, a portion of the perimeter of the sleeve, and a seal portion of the inner member.

Preferably, the inner member comprises interconnected first and second shaft portions, the longitudinal axes of which, when the inner and outer members are in a relative rest position, define a centre axis of the damper.

Preferably, a housing comprising the electromagnet is interposed between the first and second shaft portions.

Optionally, the inner member comprises a shaft about which the electromagnet is mounted. Most preferably, a diaphragm seal is provided at each end of the shaft to bound the chamber.

Preferably, the shaft is magnetically inert.

Preferably, the seal portion has an elasticity to allow the inner member to rotate in planes perpendicular to the seal portion.

Optionally, the seal portion has an elasticity to reduce at least one degree of freedom of the relative motion of the inner and outer members.

Preferably, the seal portion comprises a sprung collar and a diaphragm seal.

Preferably, the device comprises an elastic end stop to protect the device from damage induced from vibrations in the case where the electromagnet fails.

According to a third aspect of the present invention, there is provided a device incorporating a variable damper in accordance with the first aspect.

Preferably, the inner and outer members of the damper are configured to be suitable for attachment to device components, such that the application of relative forces between the components results in

corresponding forces being applied to the inner and outer members of the damper.

Preferably, a parasitic power generator is incorporated within or on the device to provide the electric current that drives the electromagnet.

Preferably, the power generator comprises a plurality of power generating units that are arrayed on the device at points where concentrated load would be expected to be applied to the device when it is put to use.

Preferably, the units comprise piezoceramic material. Optionally, the units could comprise piezoelectric unimorph or bimorph material.

Preferably, the device comprises at least one sensor that detects a variable, the value of which can be used to determine a desired amount of electric current to be applied to the electromagnetic coil.

The current applied to the coil can be varied in order to vary the strength of the magnetic field. In turn, the effective increase in the viscosity of the MRF, and hence the amount of damping between the inner and outer members provided by the damper, is dependent on the strength of the magnetic field. Thus, the desired amount of electric current that is determined when a particular value of the variable is detected can be representative of the desired

amount of damping that should be applied given that value.

Preferably, an intelligent control unit (ICU) is provided, which is capable of receiving input signals from the sensors and outputting command signals to the damper.

Preferably, an algorithm is used by ICU to determine a desired relationship between the input signals and the command signals.

Preferably, the device is a snowboard, one of the outer member and inner member of the damper is attached to the surface of the board, and the other of the inner member and outer member is attached to a raised portion formed on the board.

Preferably, the centre axis of the device is transversely oriented with respect to the longitudinal axis of the board.

Preferably, the centre axis of the device is parallel with the longitudinal axis of the board.

Preferably, a plurality of dampers are attached to the board. Dampers may be provided which have a mixture of centre axis orientations as above.

Preferably, torsion forks are provided on the board and connected to the inner member of the device to enable control of torsional stiffness of the board.

Preferably, a piezoceramic power generating unit is provided at a binding assembly.

The binding assembly is the point at which a boarder would clip their boots into the board.

Optionally, the device is a golf club, one of the outer member and inner member of the damper is attached to the shaft of the club, and the other of the inner member and outer member is attached to or forms the grip of the club.

Optionally, the device is a handle which is a component of a machine.

Such a "machine" may include, for example, a tennis racket, polo mallet or other sports implement, or may be a household tool such as a power drill, or may be a bicycle or motorcycle, with the device being the handlebar.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 shows a partial cross-sectional view of a variable damper in accordance with a first embodiment of the present invention;

Fig. 2 shows a side view and a sectional view of a variable damper in accordance with a second embodiment of the present invention;

Fig. 3 shows an isometric section of a sprung collar used in the damper of the damper shown in Fig. 2;

Fig. 4 shows a side view and a sectional view of a variable damper in accordance with a third embodiment of the present invention;

Fig. 5 shows an isometric section of the damper illustrated in Fig. 4;

Fig. 6 shows a sectional view of a variable damper in accordance with a fourth embodiment of the present invention;

Fig. 7 is an isometric view of an integrated spring used with the damper illustrated in Fig. 6;

Fig. 8 shows a snowboard incorporating two variable dampers;

Fig. 9 shows a plan cutaway view of a variable damper in accordance with a fifth embodiment of the present invention, mounted transversely on a board;

Figs. 10 and 11 illustrate how the damper of Fig. 9 is mounted on a board;

Fig. 12 shows a partial cross sectional view of a variable damper in accordance with a sixth embodiment of the present invention, mounted longitudinally on a board;

Fig. 13 illustrates how the damper of Fig. 12 is mounted on a board;

Fig. 14 shows a control schematic for the damper as illustrated in Fig. 9;

Fig. 15 shows a control schematic for the damper as illustrated in Fig. 12; and

Fig. 16 illustrates a seventh embodiment of a variable damper, as applied for use with a golf club.

Fig. 1 illustrates a first embodiment of the present invention. A variable damper (also called an "actuator" or an "MRF device") 10 comprises an outer portion 12 and an inner portion 14. The inner portion 14 comprises a first portion 16, second portion 18, and an electromagnet 20. Power lines 22 are provided within the first portion 16 to power the coil 24 of the electromagnet 20.

The first 16 and second 18 portions have seals 15, which, together with an inner surface of the outer portion 12 define an MRF chamber 28. When electric current flows through the electromagnet coil 24, a magnetic field 28 is induced, which has the effect

of increasing the effective viscosity of the MRF in the chamber 28, the increase being dependent on the power of current being passed through the coil 24.

Inner seals 15 and outer seals 17 together define the seal portion of the inner member 14. Any suitable form of seal may be used, suitably a diaphragm grommet seal.

Fig. 2 shows a second embodiment of the invention, which differs from that shown in Fig. 1 in that the seal portion is provided by a sprung collar 90 and diaphragm seal 92 at opposite ends of the inner portion.

Fig. 3 shows an isometric view of the arrangement of Fig. 2.

Insertion of a sprung collar between the inner axle and outer cylinder provides resistance to movement, proportional to the stiffness of the spring in a particular axis. The MR fluid, electromagnet and sleeve (or cylinder) adds control of dynamic movement.

The sprung collar provides primary control in two axes orthogonal to the central axis and secondary control along the central axis.

In an alternative embodiment, the sprung collar may be replaced by a sprung bush. This embodiment is illustrated in Figs. 4 and 5.

In further alternative embodiments which are not illustrated herein, the sprung collar may have a rectangular or square cross-section.

The incorporation of sprung collars or bushes between the inner axle and outer cylinder has a number of benefits in many applications, including;

1. To resist deflection of the inner relative to the outer up to a specified off state force.

2. To return the inner and outer to their neutral, rest separation.

3. To ensure the inner and outer do not actually touch.

4. To control axial movement.

Items 1 and 3 are conflicting requirements, so therefore, a mechanical end-stop may be additionally specified (to prevent the inner touching the outer), should it not be possible with the same spring to provide a low off state force and ensure clearance is maintained.

The spring constant does not necessarily have to be equal at either end of the cylinder. This presents the opportunity to control axial movement, with resistance to movement (between the inner axle and outer cylinder) at one end of the MRF device being

greater or less than the resistance at the other end.

Fig. 6 shows a third embodiment of the present invention, in which diaphragm seals are provided as part of a piston. The seals are connected by the input shaft which runs through the electromagnet. Fig. 7 shows an isometric view of this embodiment.

The control volume of MR fluid is constant between a fixed electromagnet (EM) core and the magnetic flux return guide (see figure 6). The electromagnet is fixed inside the outer cylinder - mounted inside the steel sleeve that acts as the magnetic flux return guide. The input shaft (connected to the vibration source) runs through the centre of the EM core, with opposing diaphragms connected to the shaft and sealing the system. Movement of the input shaft relative to a fixed outer cylinder (connected to the structure to be damped against) results in a pressure change in the MR fluid chamber - driving the fluid around the fixed EM core, in the annular orifice between the core and the sleeve.

Activation of the electromagnet controls the flow of MR fluid around the electromagnet. Increasing power to the electromagnet results in an increase in apparent viscosity of the MR fluid between the EM core and sleeve. Exposing the control volume of MR fluid to a variable strength magnetic field enables the control volume to act as a flow control valve. Increasing resistance to fluid flow enables the

device to absorb more energy from vibration induced movement of the input shaft relative to the outer cylinder.

Connecting the input shaft to opposing diaphragms (with a solid collar around the input shaft at either end, to act as a piston) ensures pressure induced by movement of the input shaft is equal in both directions (i.e., up and down when considering figure 6)

The movement of fluid from regions experiencing relatively small magnetic field into the control region helps to reduce degradation in the performance of the fluid (i.e., as a result of in-use-thickening).

One primary and two secondary degrees of freedom can be controlled with the connected diaphragm actuator. The primary degree of freedom is with the input shaft reciprocating relative to the outer cylinder (i.e., up and down when considering figure 6). Additionally, pitch and yaw about the common central axis of this axis-symmetric actuator can be controlled (i.e., limited rotational movement about two axes orthogonal to the common central axis). This is largely possible due to specification of a diaphragm seal, which is a fundamental part of the piston that induces pressure driven flow of the MR fluid around the EM core.

The input shaft runs through the electromagnet core, but is not connected to it (see figure 7). To achieve control in three degrees of freedom the input shaft is machined from a magnetically inert material, so that its movement is not influenced by the electromagnet.

Control of movement of the input shaft relative to the outer cylinder may be advantageous. This can be achieved by guiding the input shaft through the EM core. A sprung collar / bush between the outside diameter of the input shaft and the inside diameter of the EM core can be specified to control movement of the input shaft against the EM core (i.e., lateral movement when considering figure 6).

Additionally, damper mounts (illustrated in figure 6) on the outer cylinder may be made from rubber and specified to act as an end-stop to prevent movement of the structure connected to the input shaft against the structure to which the outer cylinder is fixed. Therefore, rubber damper mounts around the outer cylinder can act as a mechanical failsafe, should the electromagnet fail. Due to the damage that may be caused should a vibration control system fail, such a mechanical failsafe should be considered a necessity in a number of applications of the device.

Reference is now made again to Fig. 1, bearing in mind that reference to components in Fig. 1 can also

be applied where appropriate to the other embodiments illustrated.

Controlling the viscosity of the MRF means that the damping of relative motion between inner and outer portions 12, 14 can be controlled.

A steel (or other magnetically conductive material) sleeve 30 is mounted internally in the outer portion 12, which provides a flux return path through the electromagnet 20 for the magnetic field. This has the effect of concentrating the magnetic field in a region 32 between the inner and outer portions 12, 14, defining a control volume of MRF within the chamber 28 that acts as a control region. It is the variation of the viscosity of this control volume that is critical to controlling the damping. MRF in the remaining volume of the chamber 28 is not activated by the magnetic field when it is applied.

The chamber 28 is bounded by the outer member 12, rather than the sleeve 30. Thus, the volume of the MRF in the device is larger than the control volume.

This ensures that fluid in the control volume can be recycled with fresh fluid as the inner member 14 is moved relative to the outer member 12, the MRF in the control volume being moveable away from the electromagnet to a region of the MRF chamber that is substantially outside the magnetic field. This re-circulation of the fluid reduces the likelihood of

fluid-particle separation and in-use thickening, to improve the longevity of the device.

The housing that includes the sleeve 30 can be made from a single component, where the outer housing is made from steel and provides the field return path (Fig. 9), or up to three components, where the steel sleeve 30 is assembled between split cylinder that makes the outer housing (Fig. 1).

This simple construction reduces the number of moving components, making the damper 10 easy to manufacture, and also making it durable.

The electromagnet comprises copper wire wound around a steel core mounted on an inner axle. Therefore, the magnetic flux generator is axis-symmetrically mounted with the MR fluid between it and an outer cylinder to which a steel (or other magnetically conducting material) cylinder is internally mounted - providing a flux return path (to the electromagnet, through the MR fluid).

Mounting the electromagnet on the axle is considered the most power efficient means of generating magnetic field in the system. Prior devices, in which a coil is wound around the outer cylinder with a magnetically conductive piston mounted on the axle to complete the magnetic circuit, require considerably more power in order to generate a comparable magnetic field with the device thus constructed.

The embodiments shown provide for multi-axis control. Two translational degrees of freedom are provided, as the inner portion 14 translates in a direction along an axis running from left to right of the device 10, or in a direction along an axis extending normal to the page, as illustrated in Fig. 1.

When a magnetic field is applied, the resistance to this relative translational motion that is provided by the MRF is known as a pressure driven flow mode.

Activation of an electromagnet produces an apparent change in viscosity in MRF exposed to the generated magnetic field. As the MR fluid becomes more viscous, more force is required to generate a pressure that causes the fluid to flow around a constriction. The movement of the electromagnet on the inner axle relative to the outer steel sleeve creates a constriction and (pressure driven) fluid flow can be controlled (like a valve) as the electromagnet activates the MR fluid.

There is also a rotational degree of freedom for relative rotation about a central axis 34 of the device 10.

When the two portions 12, 14 attempt to rotate relative to each other in this way, the MRF resists the movement by a shear force that is induced at the surfaces of the chamber 28. This can be known as

the direct shear mode of damping control. The strength of resistance to motion offered by the direct shear mode is much less than the strength offered by the pressure driven flow mode.

The inner member 14 comprises a first portion 16, a second portion 18, and a housing containing the electromagnet 20. These portions are integral, and the longitudinal axes of the first and second portions are in-line and define a central axis 34 both of the inner member 14 and the device 10.

Seals 15, 17 provide sufficient elasticity for the shaft of the inner member to rotate about an axis running into and out of the page of the device as illustrated in Fig. 1 (i.e. moving clockwise/anticlockwise in the figure), and about an axis running from left to right horizontally as illustrated in Fig. 1 (i.e. tilting into and out of the page in the figure).

Movement between the inner 14 and outer 16 portions in a direction along the central axis 34 of the device is limited in its extent by the seals.

Spring return to the neutral position results from the viscoelastic property of the seals / with sprung collars located between seals, against the inner and outer (i.e., in the space between the shaft and the outer housing).

Thus, the two translations at right angles to the shared central axis (of the inner axle and outer cylinder), plus pitch and yaw about the same axis can be considered as being four primary degrees of freedom that can be controlled, while one translation of the inner member relative to the outer member along the shared axis and one rotation about the same axis (assuming the diaphragm seal is assembled to rotate with the inner axle) can be considered as two secondary degree of freedom can be controlled. The secondary degrees of freedom are limited by the seals.

One advantage of the damper described above lies in its ability to provide control of dynamic movement over a range (i.e., a control bandwidth). The control bandwidth is between the off state (no power to the electromagnet; fluid not activated) and the on state (electromagnet fully on; fluid fully activated).

It is important that off-state force is sufficiently low for the control bandwidth of the MRF device to act over the operating range of the product to which it is fitted. Should the off-state force (required to move the MRF device) be outside or near the upper limit of the operating range, the control bandwidth of the MRF device is of little benefit to the product to which it is fitted, and a passive vibration control solution would be better considered.

A low off state force capability can be achieved by:

1. Reducing the viscosity of the MR fluid, while avoiding significant reduction in the % volume of carbonyl iron content (that would reduce the on state capability).
2. Increasing the gap between the electromagnet and the steel sleeve / cylinder, without increasing the gap to an extent that the magnetic field strength (generated with the electromagnet activated) becomes dissipated - i.e., reducing the on state capability.
3. Specifying seals with sufficient elasticity to maintain the MR fluid stays in the outer cylinder, but avoids significant energy being absorbed by the seals as the inner is forced to move relative to the outer.

The MRF device of the present invention operates with a low viscosity fluid to ensure a low off state force is maintained. Concerns with settling and in-use-thickening (where the activated MR fluid degrades to a paste-like consistency) are significantly reduced if the MR fluid in the control volume and particularly the control region can be re-circulated (i.e., with MR fluid not exposed to the magnetic field).

The variable damper of the present invention has a wide range of applications, and the scope of the invention should not be construed as being limited to a particular application. As a particular

example, the invention will now be described as is incorporated in a snowboard.

This application is shown generally in Fig. 8. A board 40 has bindings 42 with shim portions 44, to which the outer portion 12 of a damper (or "actuator") 10 is attached. The inner portion 14 of the damper 10 is attached to the board 40. Torsion forks 46 are also mounted on the board 40, and are also in communication with the inner portion 14 of the damper 10.

As is described in more detail below, sensors monitor dynamic movement and provide input to an intelligent control unit (ICU) made up of one or more microprocessors. The response (i.e., energy absorbing capability) of the MRF actuator(s) controls dynamic movement of the product with a view to optimising performance/tuning the system to suit the operator (player).

The multi-axis system subject to this application aims to provide a wide bandwidth of semi-active damping. The system will enable the level of vibration energy absorption to be adapted with respect to vibration impulses (i.e., the product of force and time) and can be tuned to suit the user.

Soft flex, torsionally flexible boards are easier to turn and better to control at lower speeds and are generally better off piste. Stiff, torsionally rigid boards have greater stability at speeds and

have enhanced carving ability - making it easier to place the board in a turn at speed. The present invention is capable of adapting the stiffness and torsional characteristics with respect to speed and snow condition. This is achievable by using integrated sensors to monitor the amplitude and time response of vibrations that can be used to characterise speed and surface condition, with an algorithm programmed into a microprocessor controlling power supply to the electromagnets that adapt the energy absorbing capability of the MRF actuator(s).

The actuator must be mounted so that torsional and longitudinal movement of the board can be transmitted through the actuator.

For a snowboard, the actuator can be mounted with its central axis 34 either transverse or parallel ("in-line") to the longitudinal axis of the board 40.

Fig. 9 shows a fifth embodiment of the present invention, namely a transversely mounted actuator 50. Components of the actuator 50 are similar to the components referred to in Fig. 1 and shall not be hereinafter described in detail. The reference numerals that apply to Fig. 1 can be taken to refer to the corresponding components in Fig. 9. The same comments apply for the sixth embodiment illustrated in Fig. 12, which is described below.

The sprung collar illustrated in Figs. 2 and 3, or the bush illustrated in Figs. 4 and 5, are not essential parts of the MRF device when it is incorporated in to a snowboard, as the board acts as the spring that is to be controlled. MRF devices with sprung collars or bushes would add to the stiffness matrix of the board and provide adaptive semi-active control of dynamic movement. On the snowboard, the actuator is returned to a neutral position as the board relaxes after being deflected (assuming the board does not become permanently deformed).

Fig. 9 is a plan view of a transversely mounted actuator 50. The electromagnet 20 is powered by power supply 52. The MRF chamber 28 is attached to the board 40, and the outer portion 12 of the actuator 50 is attached to the shim 44 (not shown).

Steel sleeve 54 is attached to the outer cylinder 56 of the outer member, and has the shape of a cylindrical body portion with two washer shaped end portions at each end of the cylinder, the outer edges of which are in line with the outside perimeter of the body portion. The electromagnet 20 is mounted on an axle and positioned inside the steel cylinder 54.

The inner axle and outer cylinder share a common axis. There is an defined gap between the electromagnet and the steel cylinder, comprising a first dimension X, being the distance between the

end of the electromagnet 20 and the inner wall of the steel cylinder 54, and a second dimension Y, being the distance between the inside diameter of the steel cylinder 54 and the outside diameter of the electromagnet 20.

The gaps as defined by the dimensions X and Y enable the device to control up to six degrees of freedom.

To minimise the off state force, X and Y should be made as large as possible, bearing in mind that their increase will result in a corresponding decrease in the force that can be provided by the device once the full on state is applied.

Fig. 10 and 11 show perspective views of the actuator 50, showing how the torsion forks 46 are connected to the inner portion 14.

The MRF actuator 50 can adapt semi-active damping of torsional and longitudinal movement with a combination of the pressure driven flow (/ valve mode) and direct shear mode of the MR fluid being applied.

Fig. 12 shows a sixth embodiment of the present invention, namely an actuator 60 that is mounted in-line with the board 40.

The electromagnet 20 is powered by power supply 62. The MRF chamber 28 is attached to the board 40, and

the outer portion 12 of the actuator 60 is attached to the shim 44.

Fig. 13 shows a perspective view of the actuator 60, as incorporated with a board 40.

Mounted with its axis parallel to the axis of the board, the MRF actuator can adapt semi-active damping of longitudinal movement with a combination of the pressure driven flow (/ valve mode) and direct shear mode of the MR fluid being applied. Torsional stiffness can be adapted by applying the direct shear mode to resist rotation of the inner relative to the outer.

Adaptive control of the damping is provided by an intelligent control system. Fig. 14 shows an intelligent control system suitable for use with the damper shown in Fig. 9, while Fig. 15 shows an intelligent control system suitable for use with the damper shown in Fig. 12.

Integration of a parasitic power generator is preferable to powering the system from a battery. A piezo-ceramic power generator 70 (such as PZT - lead zirconium titanate) located at areas of concentrated load can be used to harvest power from deflections induced by the movement between the rider and the board.

The location of the generator could for example, be specified to be under the riders boot. For example,

the power generator could be a piezoelectric (lead-zirconium titanate - PZT) bimorph / piezoelectric (PZT) unimorph located in the minding foot-plate / between the binding assembly and the deck of the board.

This is in contrast to presently available systems, which merely use the vibration caused by movement of the board to generate power. By placing the piezo-ceramic power generators 70 at strategic points where there is concentrated load and/or movement from the rider of the board when using it, enough power can be generated to power the electromagnet and ICU.

The piezo-ceramic generator 70 located within the binding assembly (/between the binding and board) can power an energy efficient network of control-actuator(s).

An array of piezo (polymer) sensors (e.g., polyvinylidenefluoride - PVDF) sensors 72 provides a self-powered vibration monitoring capability. An array of sensors 72 located within the beam section to be controlled can provide input to the control interface on longitudinal and torsional dynamic movement produced from surface induced impulses.

This system must be sufficiently energy efficient so that the power available to the electromagnet can sufficiently change the apparent viscosity of the MR fluid, resulting in a satisfactory improvement in

dynamic control. Therefore, the number of turns on the core of the electromagnet must be sufficient to generate a satisfactory on state, but be conservative in number to conform to the power constraints. The available energy and required control bandwidth must be considered for each application.

The data provided by the sensors 72 can be used to determine the amplitude and frequency characteristics of board vibration induced as the board moves over the snow. Characteristics of the vibration can be used to determine environmental inputs (e.g., hard / soft packed snow), based on information pre-programmed into the ICU 74.

The ICU 74 controls the power supply to the electromagnet 20 such that vibration amplitude and frequency may be controlled subject to the applied control algorithm (e.g., proportional control / proportional-integral-differential control / sky-hook algorithm / to a set value - up to a definable maximum).

One or more MRF actuators may be mounted transversely, or with its axis parallel to that of the board as described above in order to provide multi-axis control.

Another major application of the present invention is the incorporation of an actuator in the grip of sports equipment, such as for example tennis, squash

or badminton rackets; golf clubs; baseball or cricket bats; or polo mallets.

Fig. 16 shows the application of an adaptive shock absorbing grips may integrated on a golf club 80.

The MRF device 10 is integrated so that the axis is in-line with the axis of the shaft 82, with the inner component mounted to the shaft 82 and the outer making up the grip. Activation of the electromagnet mounted on the structural inner component results in an apparent viscosity change in the MR fluid between the inner and outer (grip), reducing relative movement in two axes and introducing an adaptable energy absorbing capability.

A spring return to a neutral position is required. Sprung collars or bushes, such as those illustrated in Figs. 2-5, can be located between the seals, against the inner axle and outer cylinder (i.e., in the space between the shaft and the outer housing) to provide resistance to deflection that the MR fluid is able to dynamically control. Therefore, the spring is integrated in the damper assembly.

A contact plate can interface the shock-absorbing grip with the sensor-control and power supply elements of the system.

For this application, and application to handles of other devices, it is desirable to actively prevent

translation along and rotation about the shared central axis of the inner member relative to the outer member, so the off state force in these degrees of freedom needs to be raised.

This is possible by specifying seals with appropriate elasticity to prevent noticeable movement.

Again, integration of a parasitic power generator is preferable to powering the system from a battery. A piezo-ceramic power generator located at a point of concentrated load can be used to harvest power from deflections induced by the movement between the head or club, the shaft, and the handle (where the grip is located). The piezo-ceramic generator can power an energy efficient network of control-actuator(s), with piezo (polymer) sensors providing self-powered vibration monitoring capability.

PVDF sensors are proposed to provide a self-powered vibration monitoring capability. An array of sensors located within the shaft can provide input to the control interface on transmitted vibrations resulting from shock induced impulses.

A further identified application of multi-axis adaptive semi-active control of dynamic movement is in bicycle and motorbike handles. Sports bikes with low handles result in a riding position that puts weight on the rider's wrists, with fatigue compounded by any shock induced vibration that is

not sufficiently damped by the main front suspension. One or more multi-axis MRF device can be located in the bike handles as a secondary system to absorb shock and reduce wrist fatigue.

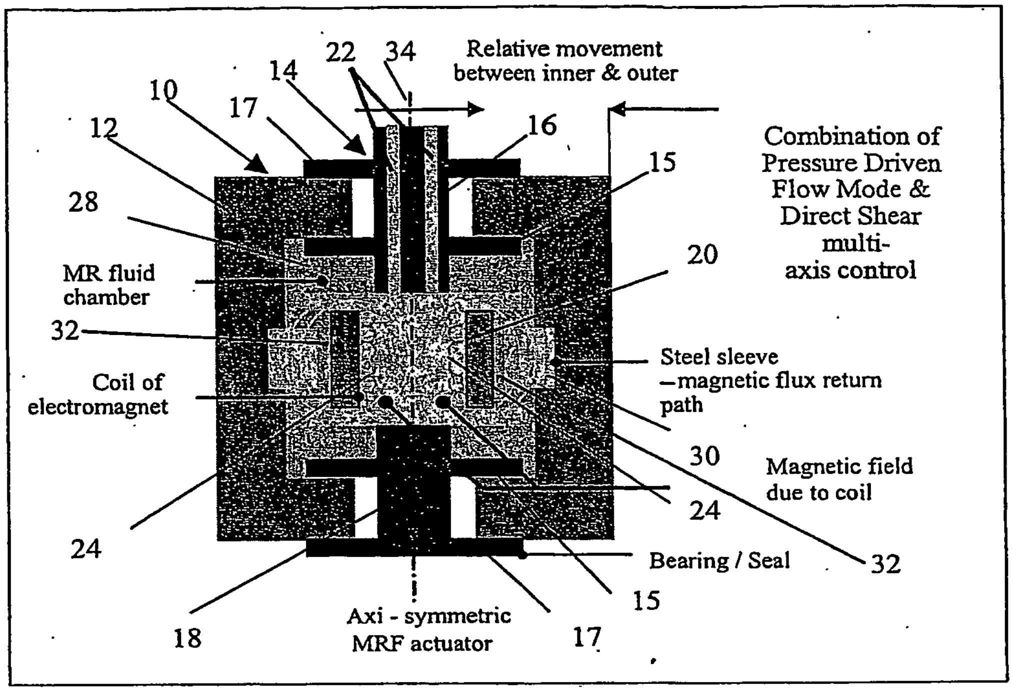
In a motorcycle application there is sufficient capacity to power the MRF device(s) with negligible performance consequences.

Applied to bicycles, although it is possible, it is advantageous not to power the MRF device(s) from the powertrain (i.e., rotation of the pedals / the wheels) as this will reduce performance. An alternative, to a dynamo powering the MRF device(s) from the powertrain, is a parasitic power generator - preferably located between the bicycle and rider, at a position, where there is a concentrated load.

A piezo-ceramic power generator located in the seat-post can be used to harvest power from deflections induced by the movement of the rider on the seat. The piezo-ceramic generator can power an energy efficient network of control-actuator(s), with piezo (polymer) sensors providing self-powered vibration monitoring capability.

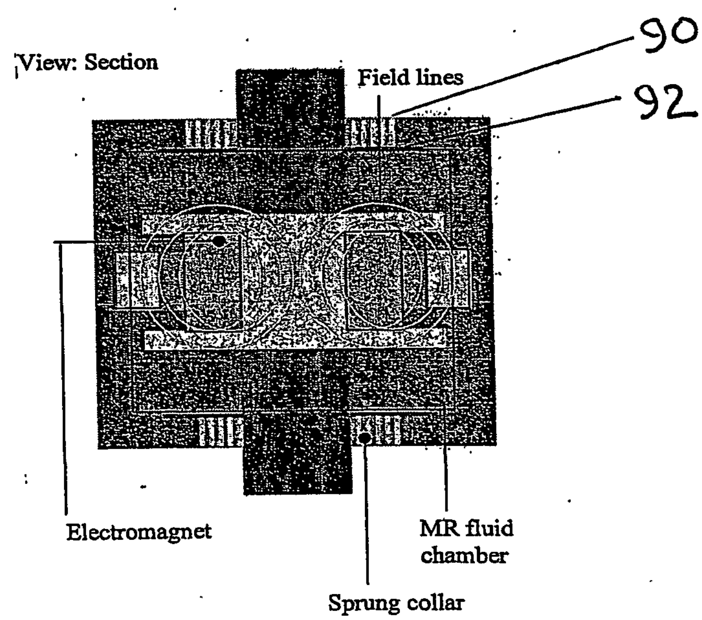
Improvements and modifications can be made to the above without departing from the scope of the present invention. In particular, the application of the invention to be incorporated in specific devices is not limited to the list of specific devices herein. Furthermore, it will be apparent that the

specific geometry of, for example, the layout of the sensor array or of the parasitic power generators may be varied as appropriate for the specific application being considered.



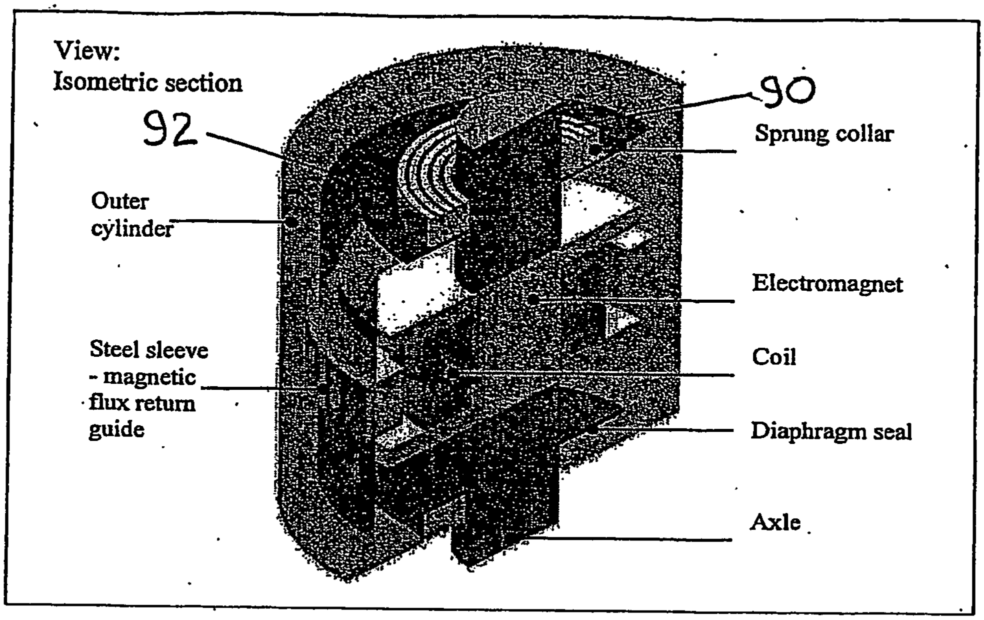
Section: multi-axis MRF device schematic

Fig.1



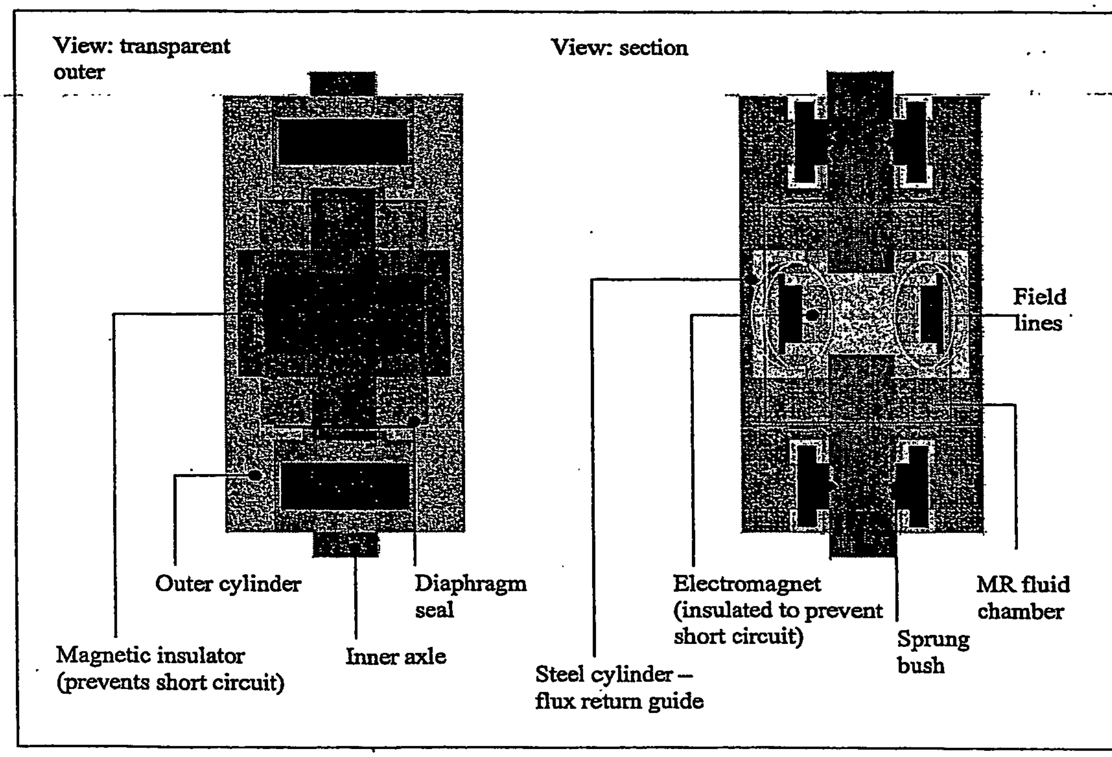
Sleeve flux return guide

Fig.2



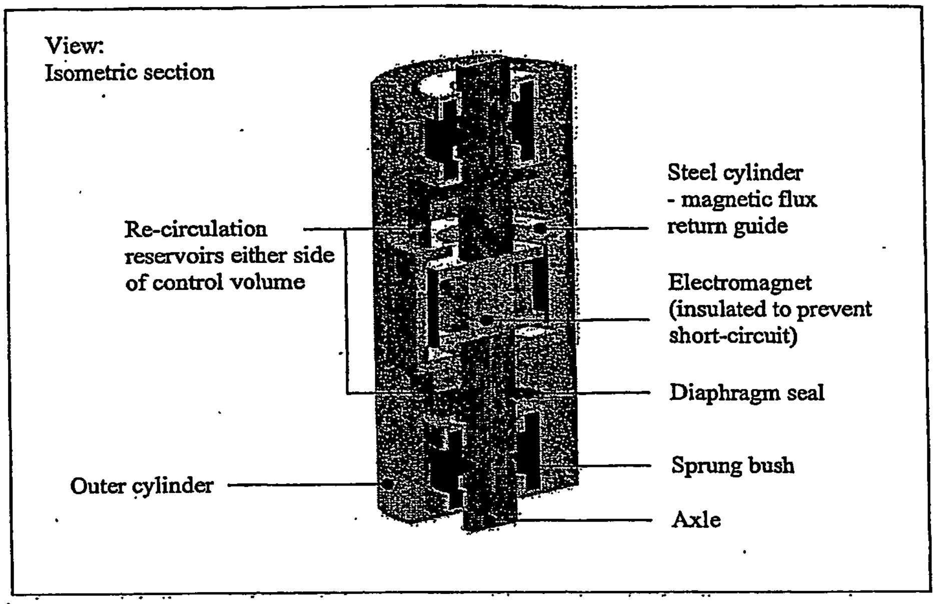
Isometric section – MRF actuator with sleeve flux return guide

Fig.3



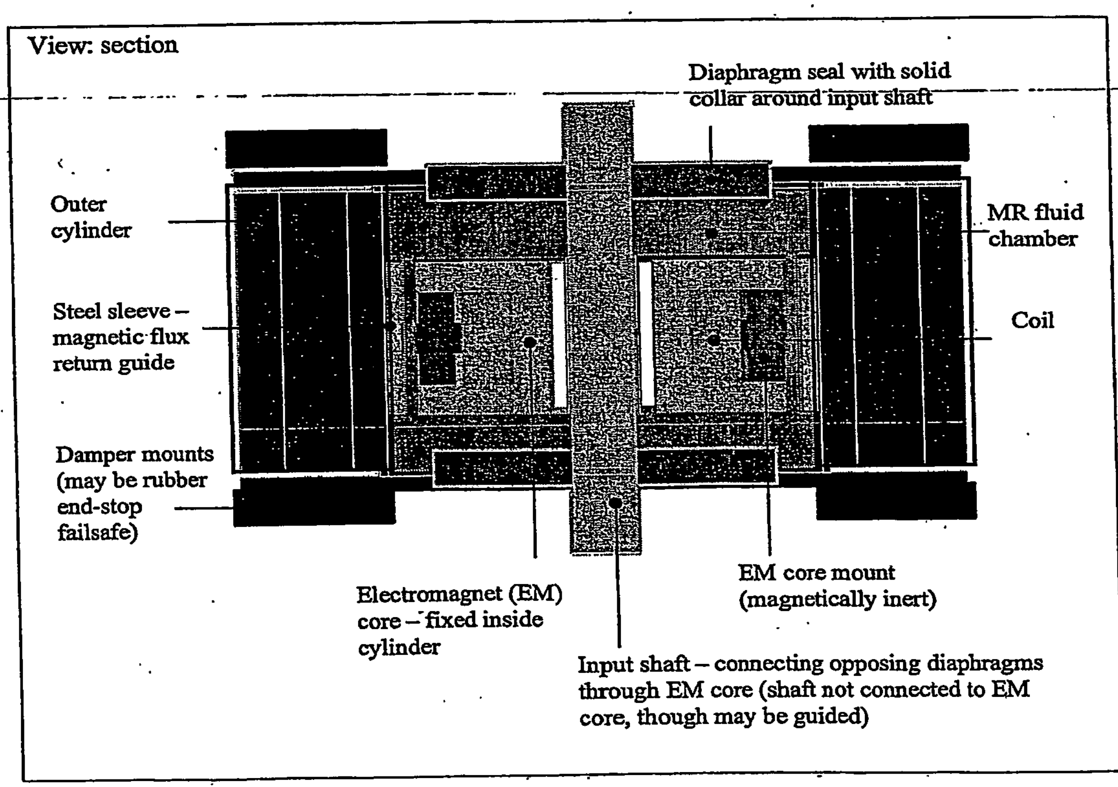
Cylinder flux return guide

Fig.4



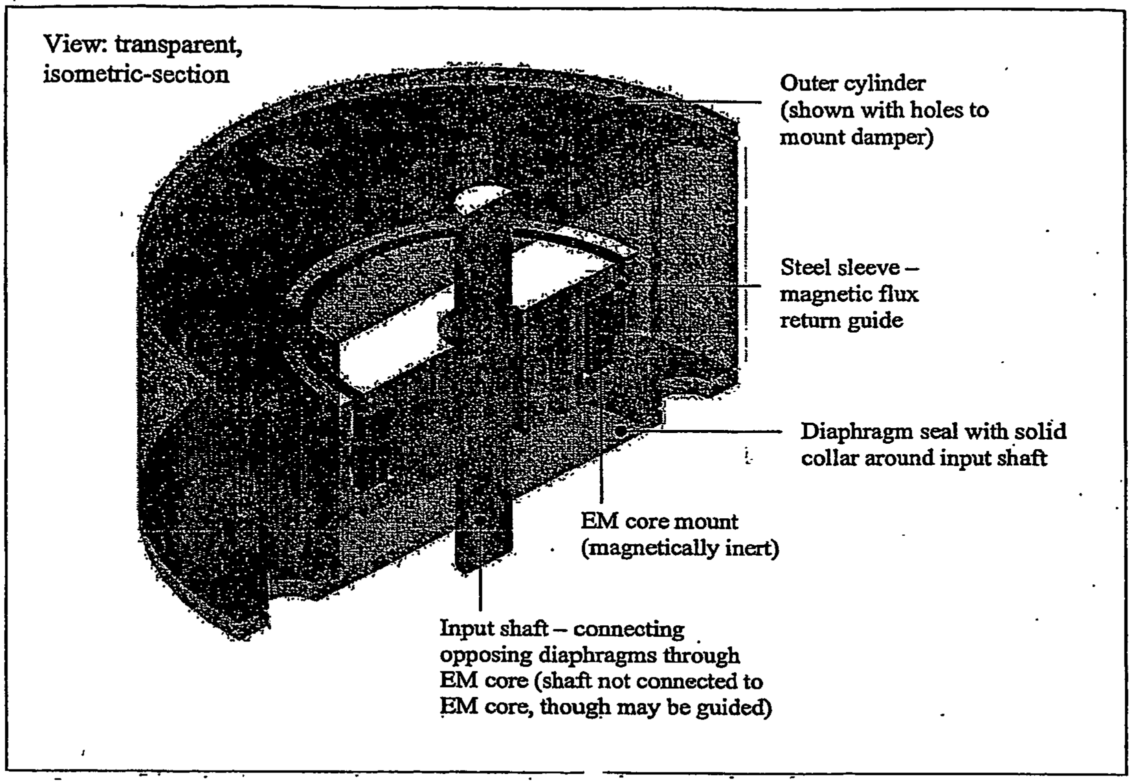
Isometric section – MRF actuator with cylinder flux return guide

Fig.5



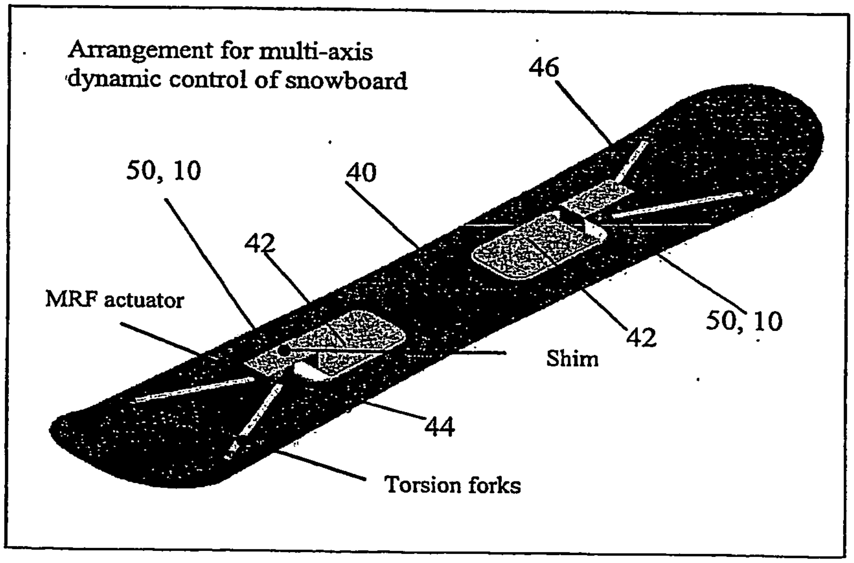
Section: connected diaphragm activated MRF actuator

Fig.6



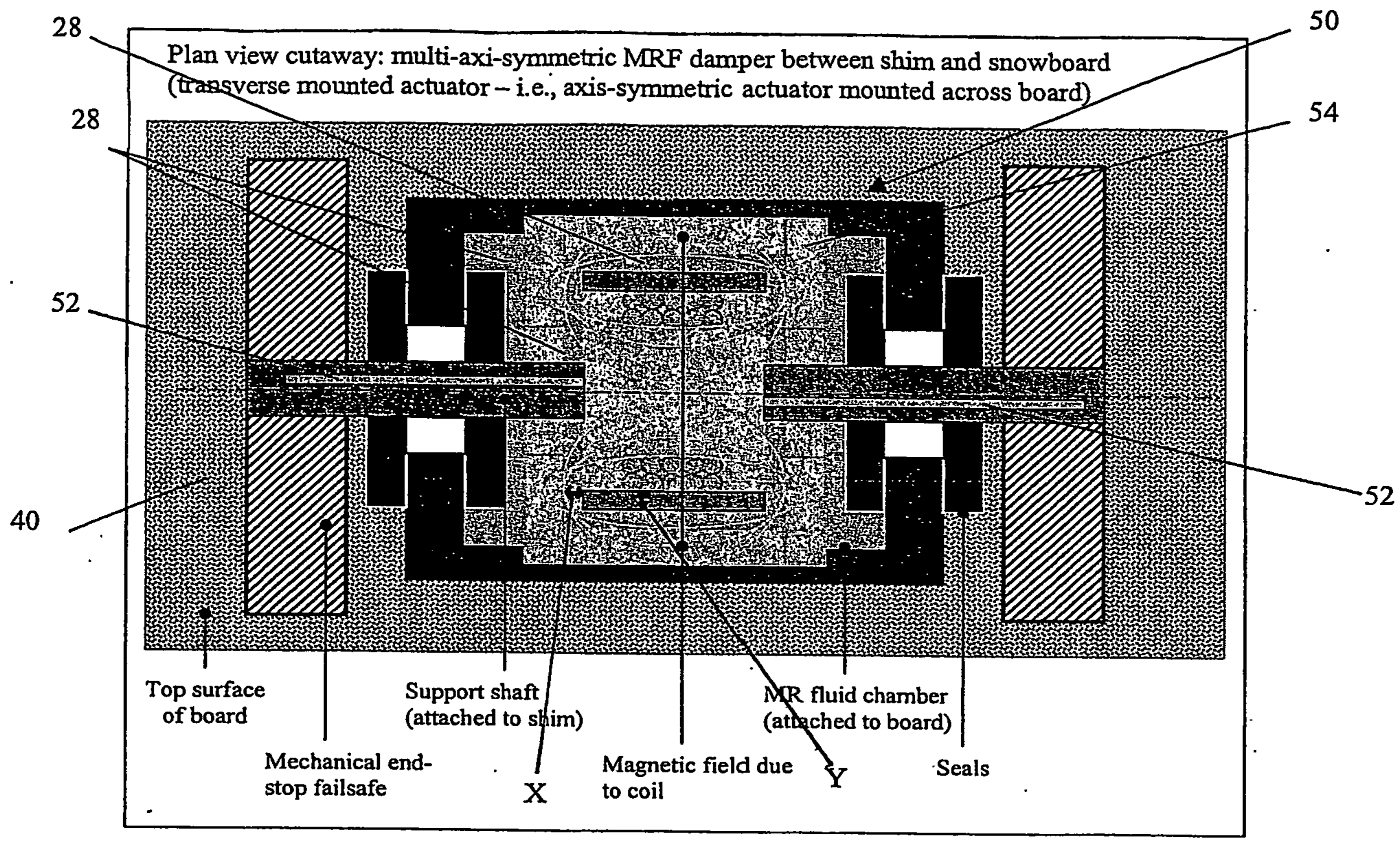
Isometric view: connected diaphragm activated MRF actuator

Fig.7



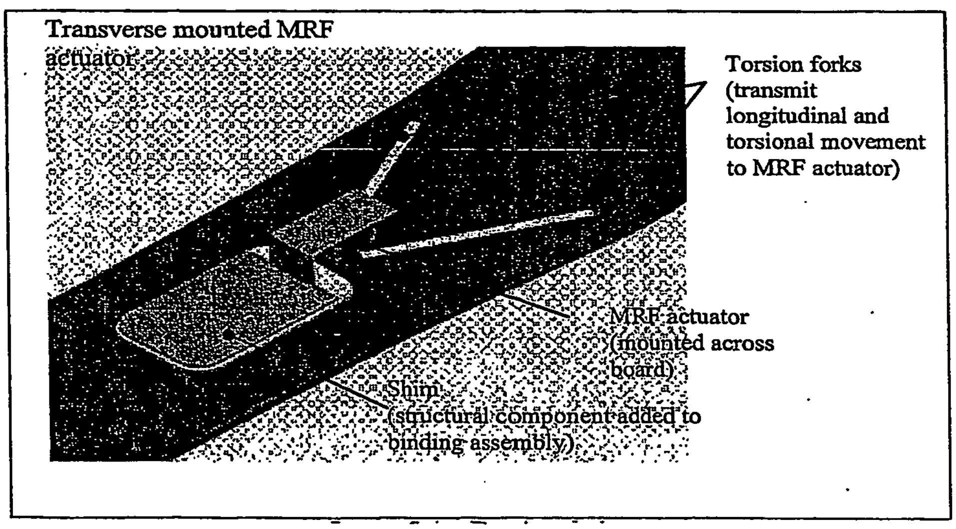
Concept 3 Snowboard

Fig.8



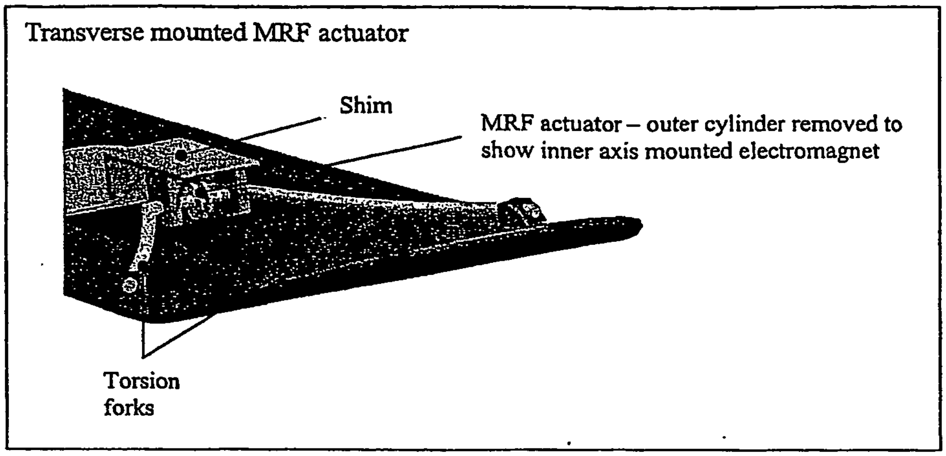
Schematic of transverse mounted actuator between shim and board

Fig.9



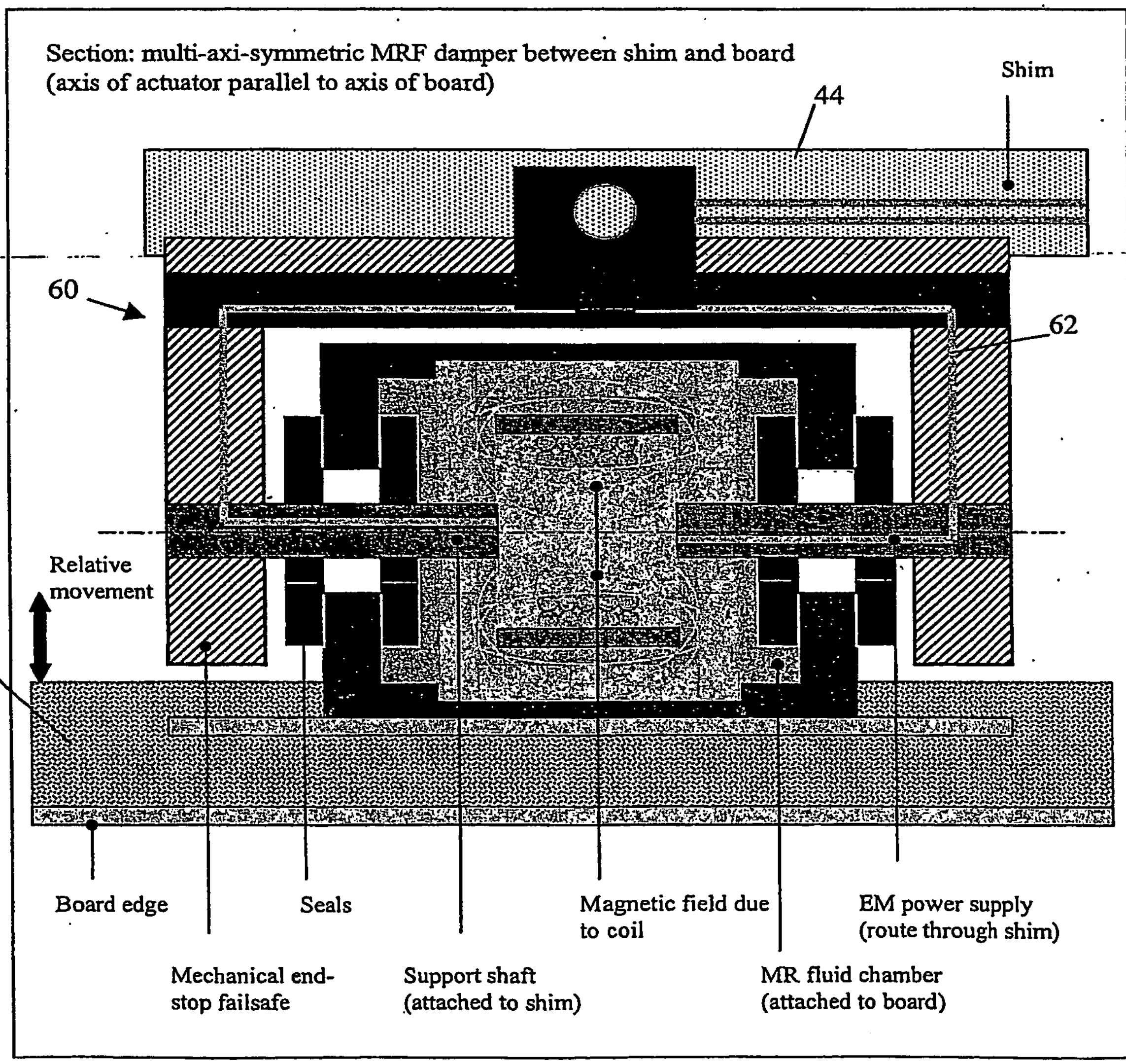
Torsion forks

Fig.10

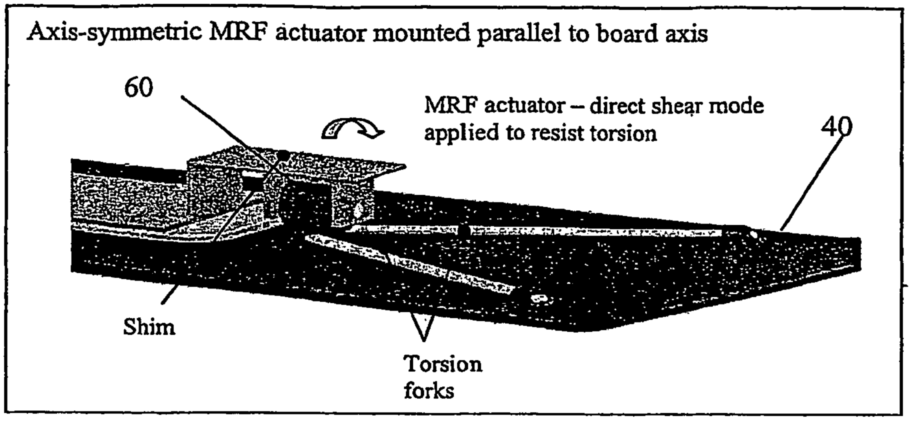


Adaptive longitudinal and torsional semi-active damping

Fig.11

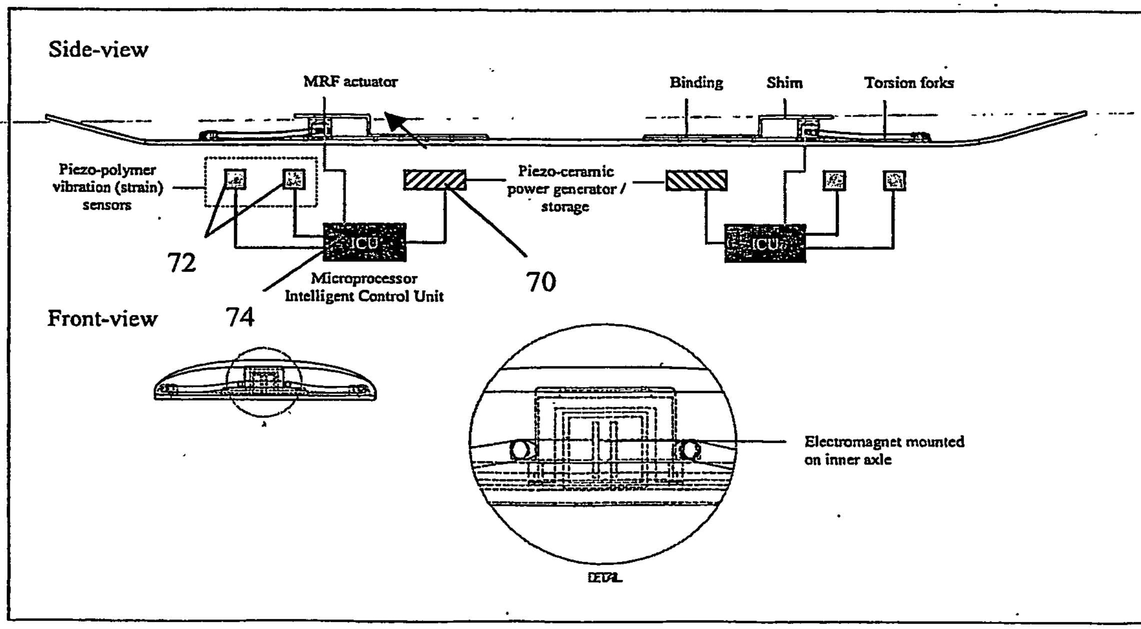


Schematic of MRF device mounted between shim and board



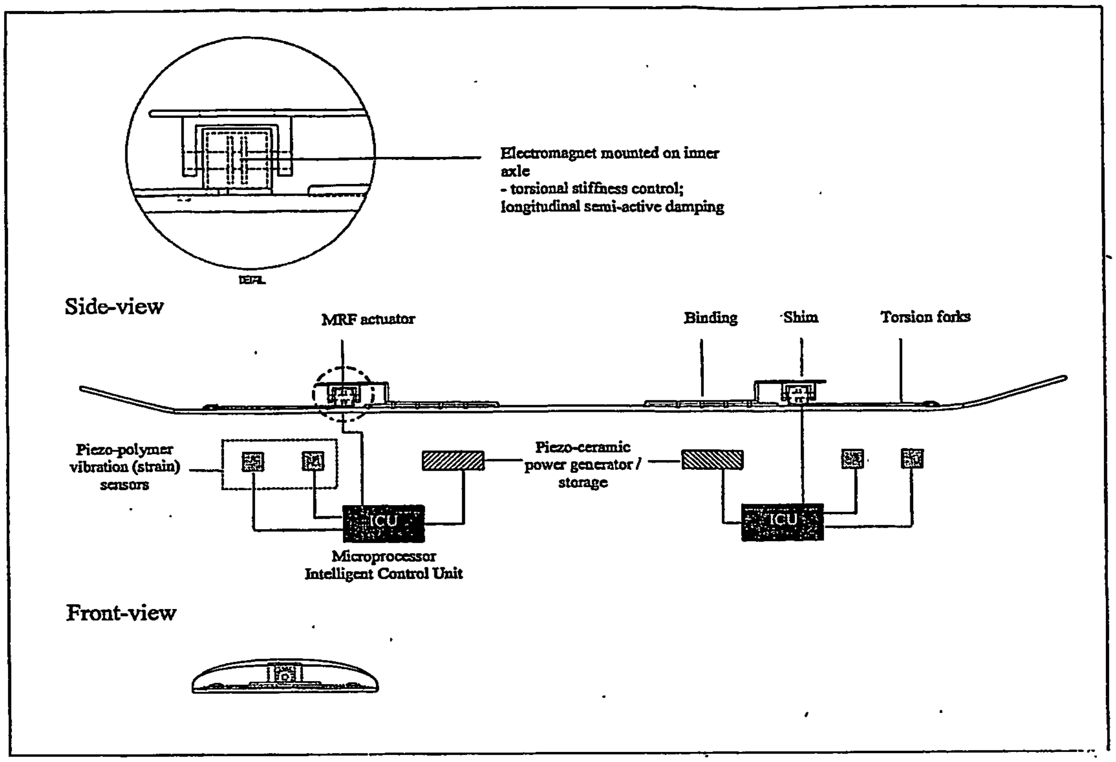
Adaptive torsional stiffness control

Fig.13



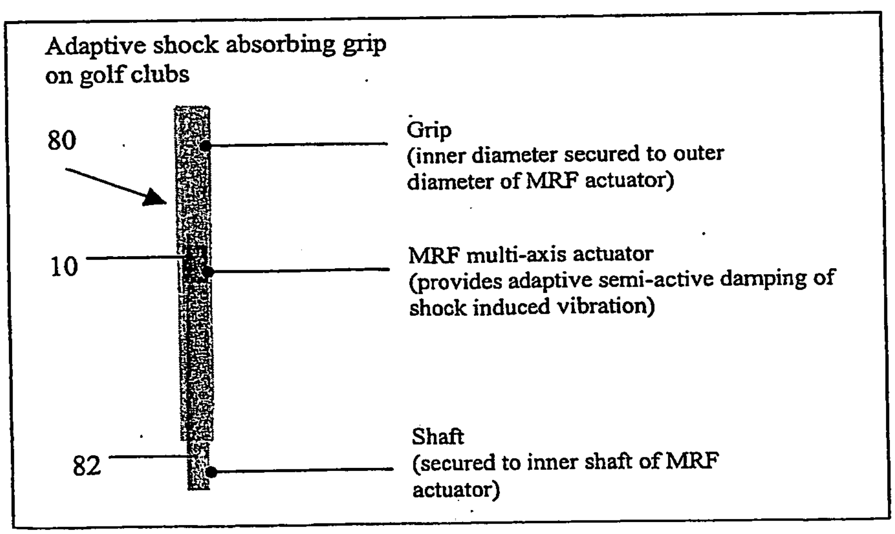
Sketch of transverse mounted actuator with control schematic

Fig.14



MRF actuator mounting sketch with control schematic

Fig.15



Multi-axis adaptive semi-active damping on golf clubs

Fig.16